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# Protective Plastic Film Removal from Stainless Steel for Reytek Corporation

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## 1. GOAL

Determine a feasible method to remove protective plastic coating from steel after $CO_2$ cutting that will enable high through put and reduce man hours spent on removing plastic by hand. Company is open to any and all ideas.

## 2. BACKGROUND

Parts are fabricated from 304 stainless steel sheet metal which is cut, using a $CO_2$ laser, into different sizes and shapes. Sheet metal is protected with a plastic coating that needs to be removed by hand in a time consuming and labor-intensive process. Plastic coating is attached to steel through use of an adhesive on the underneath of the plastic. The cut steel pieces are intended for pharmaceutical, clean room or medical environments and need to be residue free. If removal methods leave residues, then they need to be easily removed. Cut pieces range in size from very large table top too much smaller (~inches). Smaller pieces may be more time consuming to remove plastic due to large number made.

The plastic film is most likely produced by the company Novacel Inc. and is the specific film type Novacel 4228REF.[1] According to the company website and data sheets I was able to find the plastic film is composed of "polyolefins" and the adhesive that sticks to the steel is a "solvent based rubber adhesive". These are generalized ways to describe the composition of the plastic and the adhesive and is not very helpful to identify possible methods to remove it. However, it is descriptive enough to begin investigating the class of materials and possible ways to remove them. The identification of the materials was done using Fourier Transform Infrared (FTIR) spectroscopy which informed methods to remove it.

## 3. METHOD AND MATERIALS

Stainless steel samples with the plastic coating on them were obtained from the company, Reytek Corporation, after the pieces were cut using the $CO_2$ laser system they employ to manufacture their products. Fourier Transform Infrared (FTIR) spectroscopy was done using a Thermo Nicolet NEXUS 870 FTIR e.s.p. equipped with a PIKE Technologies MIRacle Attenuated Total Reflection (ATR) system with a diamond/ZnSe crystal. Heat treatments performed using a heat gun (Wagner Furno 300) or by placing steel samples flat on a hot plate (Corning PC-220 Pyroceram Stirring Hotplates) with temperature control type K thermocouple (Fluke 54-2 Dual Input Digital Thermometer). All solvents used are listed with concentrations and supplier in the Appendix A Supporting Information. For the solvent dissolution tests, small steel sample rounds were placed in glass vials, solvent being tested was added and vial was capped to prevent evaporation. Solvents listed in Table A1 in the Appendix A Supporting Information with concentrations and suppliers. Mechanical agitation of small sample rounds in solvents was done using a sonicator (VWR sonicator water bath, operating frequency is 35 kHz).

# 4. RESULTS AND DISCUSSION

To identify the polymer materials from the plastic film on the steel, FTIR was performed. This can shed light on what the material is through characteristic absorption peaks that can appear in the spectrum and potentially, also inform how to easily remove it. To start spectra were taken of the top side of the plastic coating and the black colored adhesive underside which adheres to the steel.

Figure 4-1 below shows the FTIR spectrum of the plastic film from the steel samples. The plastic film from the steel samples showed only a couple of features in the FTIR spectrum. These included two very strong peaks between 2800 - 3000 $cm^{-1}$ along with two smaller peaks at ~1450 and ~720 $cm^{-1}$. This indicates the plastic film is not very complex and is uniform in composition. By comparing the spectrum of the plastic film to spectra of different polymers a match was made which shows Novacel polyolefin was most probably polyethylene. The match in the FTIR spectra to a sample of High-Density Polyethylene (HDPE) is obvious, where the same peaks are observed for the HDPE.

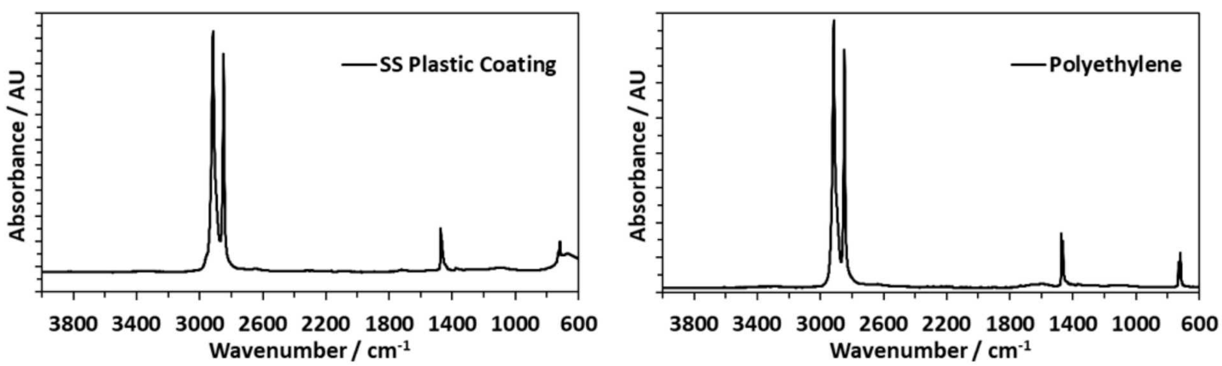


**Figure 4-1. FTIR of High-Density Polyethylene (HDPE) and plastic film from SS samples showing characteristic peaks.**

The match between the SS plastic coating and HDPE may be problematic because polyethylene is in fact a very stable polymer which is commonly used in many laboratory containers due to its chemical inertness and stability under a wide range of conditions. Conditions which will degrade and remove the polyethylene will most likely also begin degrading the steel substrate or not be easily applied in a commercial setting. Some such methods to degrade or remove polyethylene involve organic solvents at high temperatures. This is not recommended for obvious reasons of generation of large amounts of solvent fumes and possible fire hazard. Besides chemical degradation of the polyethylene (plastic film), a simple heat treatment of the steel could allow the easy removal of the film.

Using FTIR spectroscopy, the adhesive was similarly identified and found the adhesive was indeed rubber based as stated in the Novacel data sheet. Figure 4-2 shows the FTIR spectrum from the black colored adhesive side of the plastic film. This spectrum has many more peaks than the plastic side (polyethylene). Again, there were large peaks (three this time) between 2800-3000 $cm^{-1}$, but there were many more smaller peaks at lower wavenumber. The three more characteristic peaks were located at ~1440, ~1370 and ~840 $cm^{-1}$. The combination of these peaks matches what I found in literature for natural rubber.[2] There should be some solvents that can easily be used to remove the adhesive and free the steel part from the plastic coating.

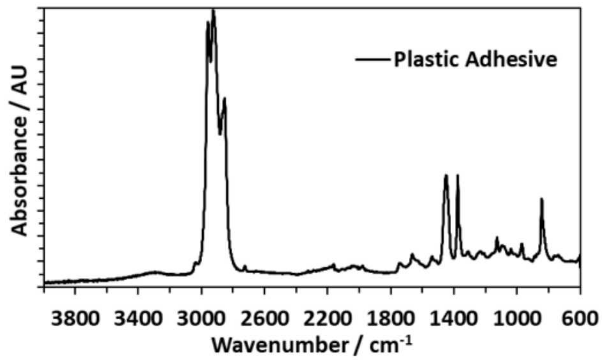


**Figure 4-2. FTIR of black colored adhesive side of plastic film from SS samples.**

The two most practical ways to remove the plastic coating from the steel is by using either a heat treatment or dissolving away the adhesive using various solvents. The first tests I tried were the heat treatments. I thought if these worked it would be the most practical for the company to employ on the large-scale products that were being produced.

Polyethylene melts in the range of 120-180 ºC (248 – 356 ºF), depending on molecular weight of the polymer chains (higher molecular weight means higher melting point). If the plastic coating is heated enough I thought perhaps it would come off of the steel on its own through a shrinking or curling action once it reached a high enough temperature. The heat treatment I tried was by using a heat gun to heat a section of the plastic coating. The Wagner heat gun, seen in Figure 4-3A, has two settings on it, a low temperature setting which is 399 ºC (750 ºF) and a high temperature setting of 593 ºC (1100 ºF). I tried the lower temperature setting first to evaluate its effectiveness. The steel took a few minutes to heat up and at first no visible changes were observed. After a few more minutes the plastic began to blacken and smoke, a representative picture is seen in Figure 4-3B. After cooling down I tried to peel the plastic off, but it did not come off easily. I tried this method a couple more times but got the same results each time. The heat gun is heating the sample unevenly and creates very hot regions where the plastic blackens and discolors.

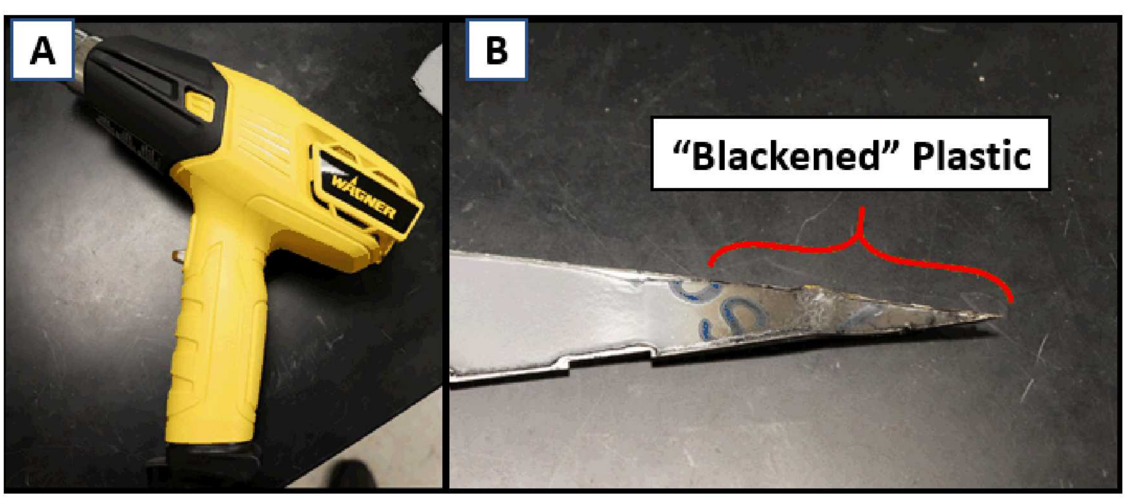

**Figure 4-3. (A) Picture of Wagner heat gun that was used for the initial heat treatment test and (B) the heat-treated sample showing the blackened plastic film after trying to remove with heat alone.**

Since the heat gun did not effectively remove the plastic and was heating the samples unevenly, I next turned to a controlled and lower temperature heat treatment method. This method used a hotplate with a variable temperature setting. I employed a thermocouple (temperature probe) with a digital temperature readout to see what temperature the hotplate and the sample were. This temperature readout allowed effective control the temperature of the sample. A picture of the hotplate and thermocouple test setup is seen in Figure 4-4. Also seen in the picture is a round steel sample with plastic film on it (next to the temperature probe).

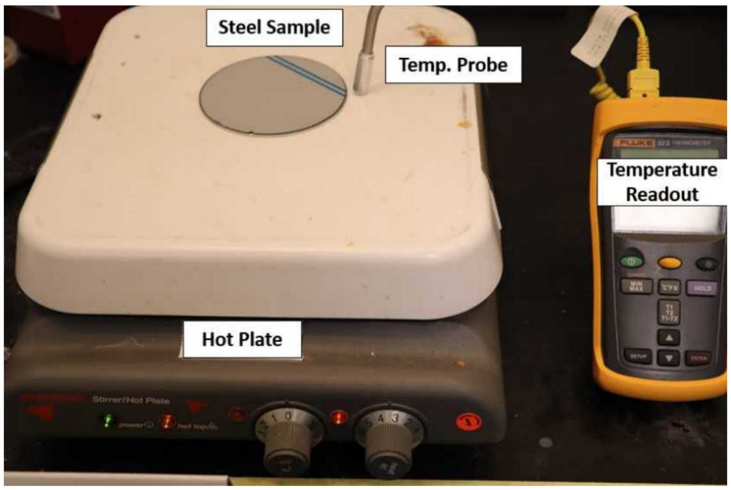


**Figure 4-4. Picture of hot plate setup with temperature read out. Steel sample is placed directly on the hot plate with the temperature probe located right next to it.**

The sample on the hotplate was slowly heated to 130 ºC (266 ºF) and monitored for any changes. At this temperature the polyethylene plastic film would melt/soften and should be easily scraped off. After sitting at this temperature for a couple minutes, the film began to appear glossy and upon gentle pressure from a flat metal spatula the film peeled up off the steel surface very easily. Figure 4-5A shows the steel sample with the temperature indicated in the lower left side. Also seen in this picture is the small area that was scraped with the metal spatula (indicated by the red arrow). Seen in Figure 4-5B and 4-5C are progressive pictures taken as I was pulling the plastic off of the steel surface with the spatula. In fact, it came very easily, and I was able to remove almost all of it simply by pulling it off with the spatula. Figure 4-5D shows the steel after the plastic was removed during the heat treatment at 130 ºC. This process worked very well, but I needed to verify that the adhesive was also removed. One condition of this work is that the steel needs to be residue free after removal.

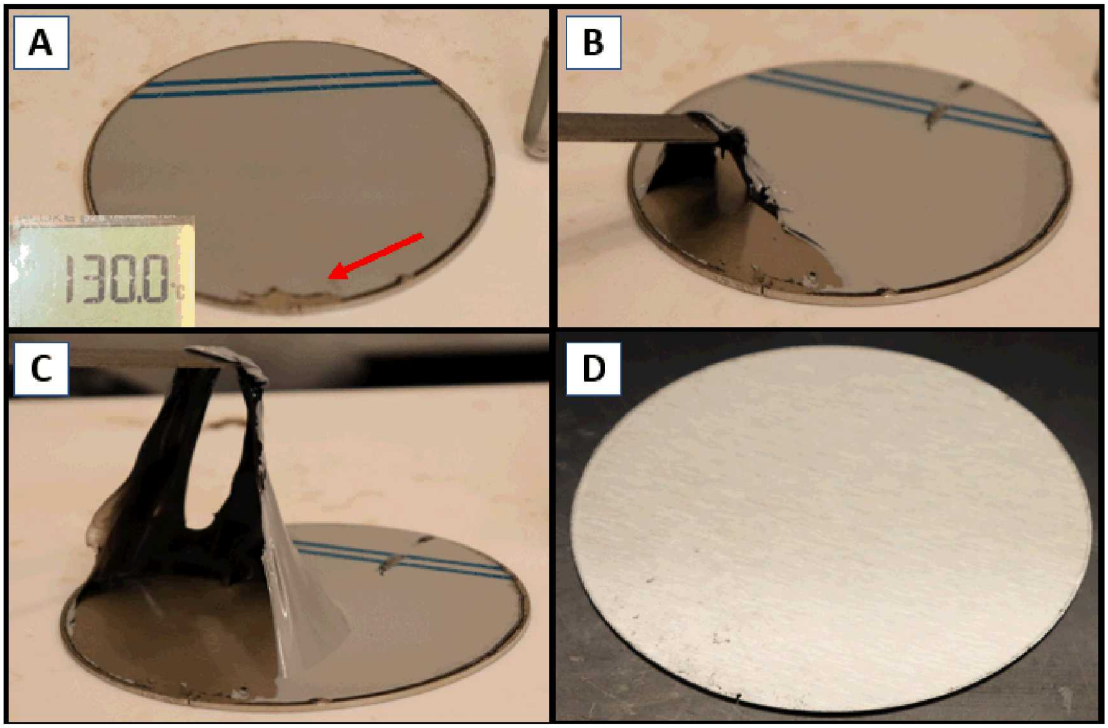


**Figure 4-5. Pictures showing plastic coated steel on hot plate at 130 ºC as indicated in picture (A). Red arrow in (A) shows section where the plastic was scraped lightly with flat metal tool. (B) and (C) show successive images of the plastic as it is easily being pulled off the steel surface. (D) shows the heated steel with plastic fully removed.**

Unfortunately, I found very quickly that there was indeed residue left on the steel plate after the 130 ºC heated removal of the plastic. The steel plate felt slightly tacky to the touch but the FTIR of the heat-treated steel plate confirmed that there was adhesive residue left on the surface. Figure 4-6 shows FTIR spectra various steel surfaces. A clean steel surface should not have any peaks in the FTIR spectra in the spectral window taken and presented here. The clean steel sample (red line), as expected, shows no peaks in this window. Also seen in Figure 4-6 is the FTIR spectra of a hand peeled steel sample (at room temperature) which shows that the adhesive residue comes off cleanly under normal processing conditions. However, the heat-treated peeled steel surface shows a dramatically different spectrum with many observed peaks. This spectrum is almost identical to that shown in Figure 4-2 of the black colored adhesive side of the plastic coating.

This confirms that during the process of the heat treatment the adhesive also melts and will not be completely removed as the plastic film is removed. This residue can be removed using an appropriate solvent (solvent data discussed below) and confirmation of this is again through use of FTIR (data not shown). However, I believe the process for heating and removing the plastic from the steel surface which then needs to be cleaned using a solvent may make it somewhat impractical considering peeling the plastic off by hand at room temperature leaves no trace of the adhesive on the steel.

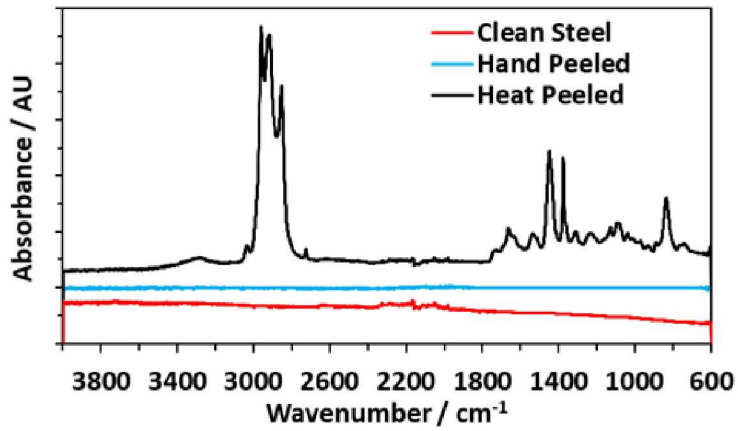


**Figure 4-6. FTIR spectra showing differences between clean steel, hand peeled steel and heat peeled steel, confirming residue is left after heat treatment to remove the plastic.**

If heated to higher temperatures the adhesive residue will blacken and begins heavily smoking, similar to what was observed with the heat gun (Picture can be seen in Figure A-2 in Appendix). After the blackening occurs, indicating a chemical change has taken place, the same solvents that were able to remove the residue before are no longer useful in removing it.

Heat treatments showed promise but ultimately may not be advantageous compared to simply hand peeling the plastic off under normal conditions. An alternative route that was investigated was using solvents to dissolve away the plastic or adhesive. The plastic, which was identified as polyethylene is not easily dissolved with common solvents. However, dissolving the rubber adhesive may be much more easily accomplished. To test the different solvents, small steel sample rounds with plastic coating (obtained from Reytek Corporation) were placed in small glass vials with different solvents. Many different solvents were tried, and Figure 4-7 shows a number of tests in the vials.

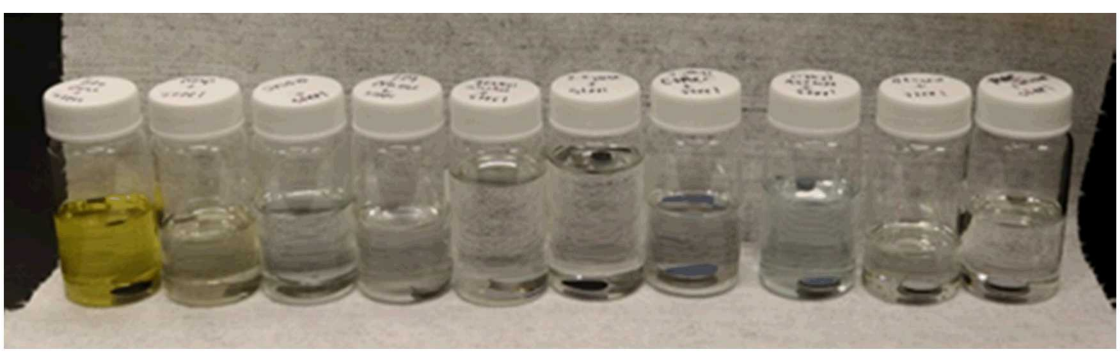

**Figure 4-7. Picture of multiple vials with steel sample rounds and solvent inside.**

To evaluate the effectiveness of the solvents I placed the steel samples into vial containing the test solvent s and immediately mechanically agitated them in a sonication bath (in the vial) and then checked on them periodically. The samples would then be sonicated after 24 hours, 3 days and then finally after 7 days. If the plastic did not come off after 7 days, the solvent was deemed unable to remove the plastic coating. The most effective solvents would cause a plastic film on the small steel round to "puckering" or "releasing" and begin coming off the steel surface at the edges first, red arrows seen in Figure 4-8B. This is presumably due to the solvent dissolving the adhesive away from the edges first, as expected for a non-porous plastic film. The pictures in Figure 4-8 show this effect and can be seen to variable, from slightly puckered to very puckered.

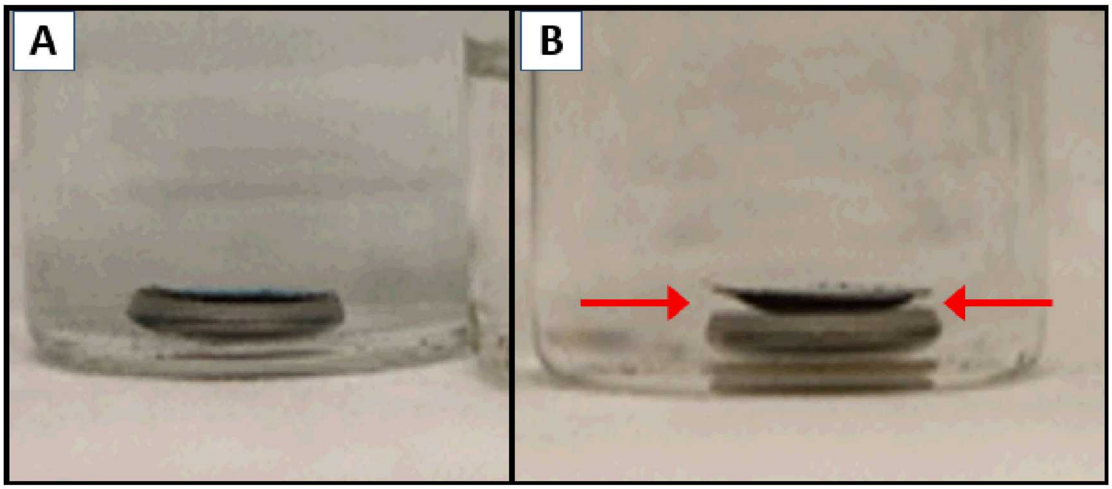


**Figure 4-8. Picture of steel sample showing variable "puckering" of the plastic cover. (A) slightly puckered and (B) very puckered.**

All the different solvents tested and their results along with any pertinent notes/observations are listed in Table 4-1. To start I began looking at the organic solvents but did not exclude aqueous based solutions. In short, the aqueous solutions did not work well. These included the 1 M NaOH (4 wt% NaOH in water), the hydrogen peroxide and the Fentons reagent. The NaOH solution was tested to determine if highly basic solutions would degrade the adhesive (it is also a component of base bath and as such needed to be determined if it had an effect) and over the timescale of these tests it did not. Both the 30% $H_2O_2$ (hydrogen peroxide) and Fenton reagent are oxidizing solutions and, it was hoped, would degrade the plastic or the adhesive. Again, no significant effects or change in the plastic was observed. A common laboratory cleaning agent is called "base bath" and is a mixture of potassium hydroxide (KOH), ethanol and a little water. This solution made the plastic film pucker a little in the beginning but ultimately failed in causing the plastic film to come off.

Some more common and less aggressive organic solvents were tested which include methanol, ethanol, isopropyl alcohol, 1-butanol (type of alcohol), acetone and ethyl acetate. All of the alcohols had no observed effect on the plastic films. Surprisingly, acetone also appeared to have no effect on the adhesive. Ethyl Acetate did remove the plastic film after ~3 days, although the question about if it dissolved the adhesive is not easily answered. The adhesive was solvated enough by the ethyl acetate to effectively remove the plastic from the steel but upon FTIR analysis it appears that the adhesive was still present on the plastic. Figure 4-9 shows the FTIR spectrum of the adhesive side of the plastic film after being removed from the steel surface by a given solvent. Both ethyl acetate and toluene are shown (additional FTIR after soaking in different solvents is presented in Figure A2 of the appendix). The ethyl acetate FTIR spectrum shows the characteristic peaks associated with the adhesive discussed previously (Figure 4-2). When compared to the toluene soaked adhesive side of the plastic film (toluene dissolved the adhesive, discussed more below) there is no sign of the adhesive and the spectra looks the same as the HDPE and the top side of the plastic film as seen in Figure 4-1.

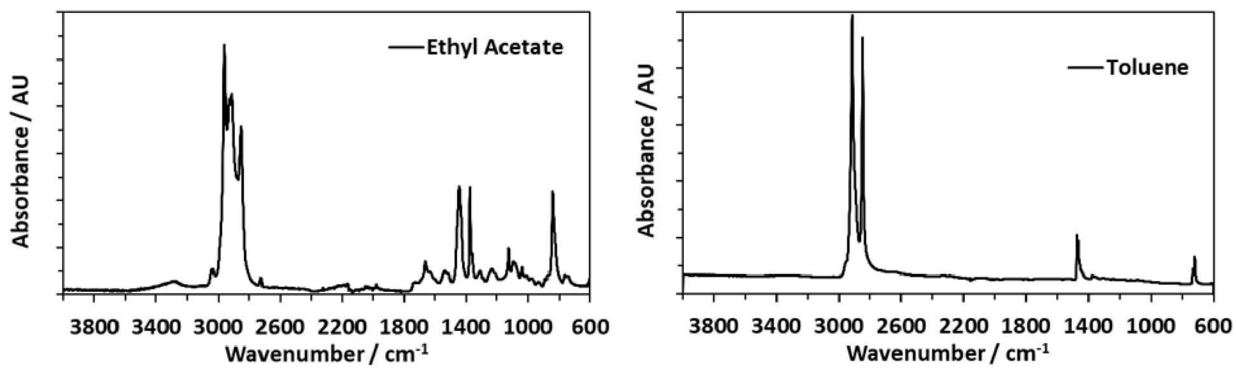


**Figure 4-9. FTIR spectra of black adhesive side of plastic film after soaking in toluene and ethyl acetate.**

Some of the less common solvents tested include; benzyl alcohol, acetonitrile, diethyl ether, dimethyl sulfoxide (DMSO) and N-methyl pyrrolidone. Also included were some more viscous solvents including; mineral oil, di-ethylene glycol ethyl ether (Carbitol) and propylene glycol monomethyl ether acetate. Surprisingly, like acetone, acetonitrile did not remove the plastic, even after 7 days. Of all of these less common solvents, only diethyl ether removed the plastic from the steel surface. However, the rate of evaporation of the diethyl ether is too fast to make it practical if it takes multiple days to remove the adhesive.

There were a number of solvents tested that worked well. Some of which fit into a generalized category based on the chemical structure, such as aromatic hydrocarbons and small chain length hydrocarbons, while some of them did not fir readily into a category. Three effective solvents that I tested, that did not fit into a category, were: Methyl Ethyl Ketone (MEK), tetrahydrofuran (THF) and chloroform. All three of these solvents removed the plastic within 1 – 2 days. THF dissolved the adhesive very quickly where the plastic was puckering in just a couple minutes and within 1 hour the plastic was released (with gentle agitation). However, I do not recommend using THF as it is a known peroxide former and can be explosively dangerous if not handled properly. The chloroform also removed the plastic as did the MEK. The MEK seemed to be very effective with puckering of the plastic observed in 30 minutes, but the plastic did not fully release in a day. It did come off after that first day with sonication.

The aromatic hydrocarbon solvents were found to work effectively and the three tested included; benzene, toluene and *para*-xylene (similar to commercially available xylenes). All three of these solvents are good at dissolving organic molecules and polymers. Structurally, they consist of a single aromatic benzene ring (benzene ring - $C_6H_6$) with hydrogen (-H) or methyl (-$CH_3$) groups combing off the ring. As benzene is the simplest with no methyl substitutions and more complex having methyl groups, toluene has 1 methyl group and xylene has 2 methyl groups at different possible positions on the ring. These three solvents all worked effectively to dissolve the adhesive and remove the plastic film. They would cause the film to pucker in minutes to hours and all solvents would cause the plastic to be removed in a day.

The best solvents I found were linear chain hydrocarbon compounds which were pentane and hexane having 5 and 6 carbon long chains, respectively. These solvents dissolved away the adhesive faster than any of the other solvents mentioned. In less than 20 minutes both solvents were able to remove the plastic film from the steel. The drawback to these however, is they tend to have high vapor pressure and evaporate away quite fast (pentane evaporated away faster than hexane). I believe butane (main component in light fluid) would also have worked but its rate of evaporation (and safety considerations) would make it difficult to use. Longer chain hydrocarbons such as heptane and octane would probably also work very well. Similar solvents (commercially available) were also tested based on these solvents discussed further below.

In order to try and prevent the evaporation of the solvents I tried mixing one with a viscous liquid that could hopefully slow the evaporation to a rate that was manageable. I mixed 50% mineral oil and 50% xylenes (by volume) and used this mixture to attempt to remove the plastic film. The mixture took some work to get entirely mixed together into a single phase. The mixture worked in removing the plastic film, but it took longer than the xylenes alone, as expected. While it did slowly pucker the plastic, it was not removed until 3 days after immersion. Critically, this increase in time to remove the plastic may lead to an undesirable amount of the xylenes evaporating off. To test this the cap was removed from the vial and after 4 days 60-70% of the xylenes had evaporated off (mineral oil is not volatile, so any evaporation is due to the xylenes). This may not be a problem if there is a seal container the solvent is put in. Due to the increased time to remove the plastic and the fact that the xylene evaporation didn't appear to be slowed, I don't recommend this procedure. This effort to use combinations was not continued do to the high evaporation rate of the xylenes pointing to similar outcomes for other high vapor pressure solvents. Additionally, after removing the plastic film, the steel would still need to be cleaned to get the mineral oil residue off.

After testing the different laboratory grade solvents for their efficacy in removing the plastic, a number of commercially available solvents were tested. These consisted of various pure solvents and mixtures that were determined to be the most promising based on the previous tests. The solvents were purchased from the local hardware store (or gas station) and used straight out of the container. Two solvents that would have worked but were not purchased commercially were xylenes and Methyl Ethyl Ketone (MEK). This is because they were tested from the laboratory grade solvents and I believe there will be no difference from the laboratory grade solvents and the commercially available ones.

The only aqueous based commercially available solvent tested was Windex. Windex was tested because of its high ammonia content and its ability to remove many sticky, adhesive residues. Ideally, if it worked, it would be well suited to use in a commercial setting to remove the plastic from large and small parts without generating flammable and hazardous fumes. The Windex solution, unfortunately, did not work, even after 7 days.

The non-aqueous commercially available solvents included; mineral spirits, V.M.&P. Naphtha, liquid de-glosser, WD-40 and Goo Gone. Of these, I expected the mineral spirits and goo gone to work very well and was unsure about the V.M.&P. Naphtha, liquid de-glosser, WD-40. The mineral spirits and goo gone are both made of petroleum distillates and I thought they would work similarly to the pentane and hexane. However, both of these did not adequately remove the plastic, both only removing the plastic by the 7 day mark. The WD-40 did not remove the plastic in the 7 day time period (plastic eventually did come off after ~ 2 weeks).

The V.M.&P. Naphtha and liquid de-glosser both worked very well. The V.M.&P. Naphtha immersion began puckering the plastic in 20-30 minutes an came off with gentle agitation. The liquid de-glosser is a combination of aliphatic naphtha and toluene (other ingredients as well) which have been shown to be effective, so it should work similarly. The liquid de-glosser dissolved the adhesive and the plastic came off in less than a day but there were no signs of puckering in the plastic. Because no puckering was observed for the liquid de-glosser, a second sample used to confirm the liquid de-glosser was effective also came off in a day.

Finally, the last commercially available solvent tested was also the most common, gasoline (specifically, regular unleaded gasoline purchased from a local gas station). The reasoning behind this test is simple, it is similar in chemical make up to the short chain linear hydrocarbons pentane and hexane (as well as maybe some aromatic hydrocarbons similar to benzene or xylene). Gasoline sold at the local gas station also has added ethanol, up to ~10%. Previous tests showed that ethanol did not dissolve the adhesive but should not severely affect the efficacy since it is only 1/10 of the volume. As expected the gasoline did remove the plastic from the steel. The plastic was observed to start puckering in <5 minutes and completely came off <2 hours later. Additionally, gasoline is much cheaper than the other commercially available solvents and can be purchased at the local gas station for a couple dollars per gallon.

**Table 4-1. Effect of solvents used. "O" indicates plastic coating successfully removed under listed conditions and "X" indicates did not remove the plastic.**

| SOLVENT NAME | 24 HRS W/ SONICATION | 3 DAYS W/ SONICATION | 7 DAYS W/ SONICATION | NOTES |
|---|---|---|---|---|
| METHANOL | X | X | X | |
| ETHANOL | X | X | X | |
| ISOPROPYL ALCOHOL | X | X | X | |
| 1-BUTANOL | X | X | X | |
| ACETONE | X | X | X | Very surprising - Acetone would not remove residue from heat treated steel |
| ETHYL ACETATE | X | O | | 6 samples tested to be sure solvent worked due to FTIR evidence that it was fully dissolving the rubber adhesive– some samples were very easily removed with gentle action with tweezers after 2-3 days |
| 1 M NAOH | X | X | X | |

| SOLVENT NAME | 24 HRS W/ SONICATION | 3 DAYS W/ SONICATION | 7 DAYS W/ SONICATION | NOTES |
|---|---|---|---|---|
| HYDROGEN PEROXIDE | X | X | X | Bubbled a little – no change |
| FENTON REAGENT | X | X | X | Vigorously bubbled – no change |
| BASE BATH | X | X | X | Sample showed slight "puckering" - did not come off |
| BENZYL ALCOHOL | X | X | X | |
| ACETONITRILE | X | X | X | |
| DIETHYL ETHER | X | X | O | boiling point too low to be practical |
| DMSO (DIMETHYL SULFOXIDE) | X | X | X | |
| N-METHYL PYRROLIDONE | X | X | X | |
| MINERAL OIL | X | X | X | |
| DI(ETHYLENE GLYCOL) ETHYL ETHER / 2-(2-ETHOXYETHOXY)ETHANOL / CARBITOL™ | X | X | X | Sample showed slight "Puckering" – did not come off |
| PROPYLENE GLYCOL MONOMETHYL ETHER ACETATE | X | X | X | |
| 2-BUTANONE / METHYL ETHYL KETONE / MEK | O/X | O | | Plastic was puckering after 30 min – still did not come off after sonication 24 hrs later – did come off with sonication after 2 days |
| TETRAHYDROFURAN / THF | O | | | Began puckering within 5 minutes – came off <1hr later with gentle agitation |
| CHLOROFORM | O | | | |

| SOLVENT NAME | 24 HRS W/ SONICATION | 3 DAYS W/ SONICATION | 7 DAYS W/ SONICATION | NOTES |
|---|---|---|---|---|
| **BENZENE** | O/X | O | | 1st– did not come off after 24hrs but did before 48 hrs -<br><br>2nd sample – puckered <24hrs after immersion and came off with gentle agitation |
| **TOLUENE** | O | | | |
| **PARA – XYLENE / XYLENES** | O | | | |
| **PENTANE** | O | | | Came off less in ~ 10-20 minutes - Pentane evaporated away too fast |
| **HEXANES** | O | | | Plastic came off in ~10 minutes – hexanes evaporate away fairly fast |
| **50% MINERAL OIL, 50% XYLENES** | X | O | | Components did not readily mix together and took some effort to combine<br><br>Uncapped: 60-70% of xylenes evaporated from mixture in 4 days |
| **"MINERAL SPIRITS"** | X | X | O | Expected solvent to work faster |
| **"V.M.&P. NAPHTHA"** | O | | | Within 20-30 minutes plastic was puckering and came off with gentle agitation/shaking |
| **"LIQUID DE-GLOSSER"** | O | | | Sonication after 24 hrs removed plastic despite no signs of puckering – 2nd sample also came off in 24hrs with sonication |

| SOLVENT NAME | 24 HRS W/ SONICATION | 3 DAYS W/ SONICATION | 7 DAYS W/ SONICATION | NOTES |
|---|---|---|---|---|
| **"WD-40"** | X | X | X | plastic did eventually come off after ~2 weeks |
| **"GOO GONE"** | X | X | O | 1st and 2nd sample came off after ~ 5 days |
| **WINDEX** | X | X | X | |
| **COMMERCIAL GASOLINE (REGULAR UNLEADED)** | O | | | Began puckering within 5 minutes and came off <2 hours later |

## 5. CONCLUSIONS AND RECOMMENDATIONS

Various ways to remove the plastic coating from laser cut stainless steel samples was investigated through combinations of heat treatment, mechanical force and chemical solvents. The heat treatment did effectively soften the plastic coating allowing it to be removed easily from the surface of the steel sample. However, as one of the requirements for this process by the company is that there will not be any residue left behind the heat treatment removal of the plastic is not recommended.

Solvent dissolution of the adhesive was done using laboratory grade solvents and a number of good options were found. After performing these various experiments and tests, commercial solvents were tested. Some suitable commercially available solvents were identified which can effectively remove the plastic. These include: ethyl acetate, V.M.&P. Naphtha, liquid de-glosser, xylenes, MEK and regular gasoline. The best performing were gasoline, V.M.&P. Naphtha and xylenes. Less effective were the liquid de-glosser, MEK and ethyl acetate. The gasoline may be the cheapest and very effective but ethyl acetate is also fairly effective, even though it didn't fully dissolve the adhesive it still affected it enough to remove the plastic, it will evaporate at a slower rate and is commonly sold in hardware stores.

This solvent based method may be more applicable to the smaller parts but if a closed container can be used to put solvent in to prevent evaporation. A large number of the parts into it for a day to remove the plastic this could potentially save the company many man hours per week. I do not know what the OSHA and state regulations are for these solvents or proper working conditions for a commercial business using these solvents. Any determination of what solvent/method to use needs to be evaluated and determined by the company based on local laws and regulations.

## 6. ACKNOWLEDGEMENTS

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## 7. REFERENCES

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## APPENDIX A. SUPPORTING INFORMATION

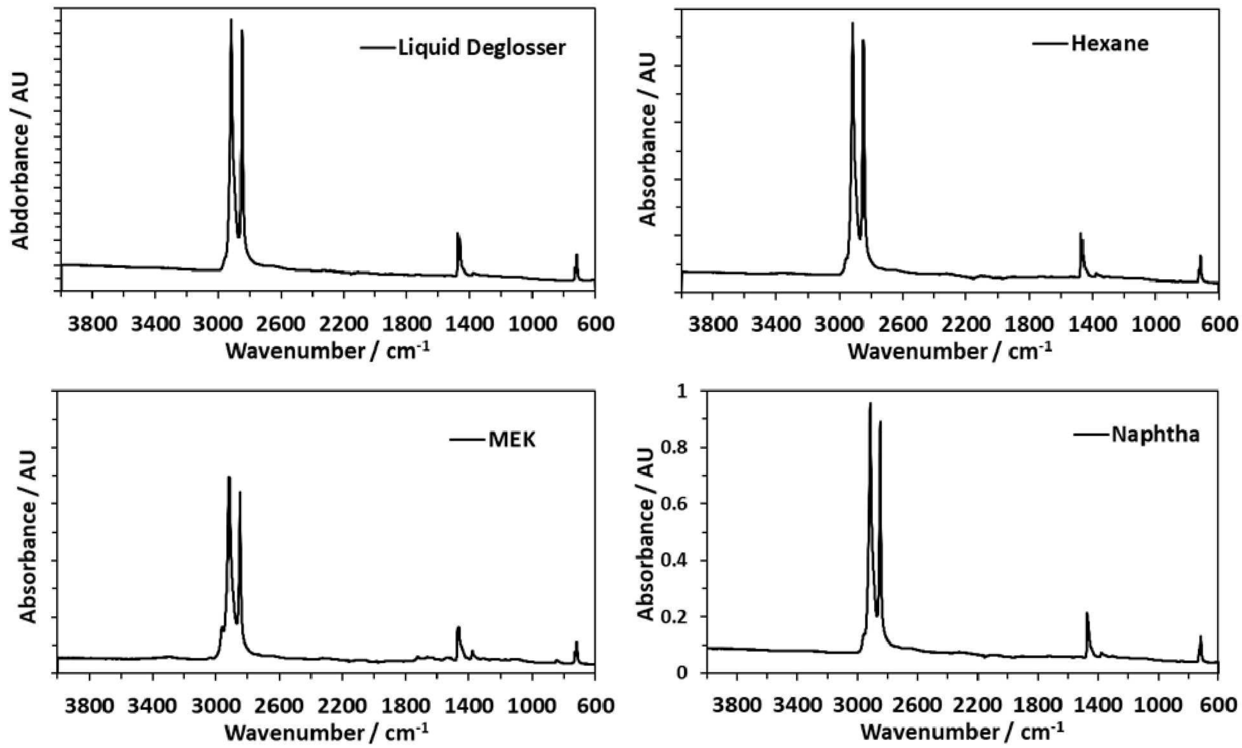


**Figure A-1. FTIR spectra of adhesive underside of plastic film after being removed from steel surface by different solvents as indicated.**


**Figure A-2. Picture of steel sample after heating to 200 ºC (392 ºF) showing the blackened adhesive residue left on the surface).**

**Table A-1: Solvents and solutions used in attempt to remove plastic coating, including concentrations and suppliers.** (*Concentrations are approximate as proprietary ingredients are not explicitly stated and commercial variations can change)

| SOLVENT NAME | CONCENTRATION OF COMPONENTS | SOURCE |
|---|---|---|
| **METHANOL** | >99% | Sigma Aldrich |
| **ETHANOL** | 200 proof | Sigma Aldrich |
| **ISOPROPYL ALCOHOL** | 70% in H2O | Sigma Aldrich |
| **1-BUTANOL** | >99% | Fischer Scientific |
| **ACETONE** | >99% | Sigma Aldrich |
| **ETHYL ACETATE** | >99% | Sigma Aldrich |
| **NAOH** | 1 Molar NaOH in $H_2O$ (40 g/liter or 4 wt%) | Sigma Aldrich |
| **HYDROGEN PEROXIDE** | 30% $H_2O_2$ in $H_2O$ | |
| **FENTON REAGENT** | 3% $H_2O_2$ with 10mM $FeSO_4$ in $H_2O$ | |
| **BASE BATH** | 1 kg KOH<br>1 Liter $H_2O$<br>1.2 Liters ETHANOL | |
| **BENZYL ALCOHOL** | >99% | Sigma Aldrich |
| **ACETONITRILE** | >99% | Sigma Aldrich |
| **DIETHYL ETHER** | >99% | Sigma Aldrich |
| **DMSO (DIMETHYL SULFOXIDE)** | >99% | Sigma Aldrich |
| **N-METHYL PYRROLIDONE / NMP** | >99% | Fisher Scientific |
| **MINERAL OIL** | N/A | Sigma Aldrich |
| **DI(ETHYLENE GLYCOL) ETHYL ETHER / 2-(2-ETHOXYETHOXY)ETHANOL / CARBITOL™** | >99% | GmbH & Co KG<br>Zschimmer & Scwarz |
| **PROPYLENE GLYCOL MONOMETHYL ETHER ACETATE** | >99% | Sigma Aldrich |

| SOLVENT NAME | CONCENTRATION OF COMPONENTS | SOURCE |
|---|---|---|
| **2-BUTANONE / METHYL ETHYL KETONE / MEK** | >99% | Sigma Aldrich / Local Hardware Store |
| **TETRAHYDROFURAN / THF** | 99% stabilized | Sigma Aldrich |
| **BENZENE** | >99% | Sigma Aldrich |
| **TOLUENE** | >99% | Sigma Aldrich |
| **PARA – XYLENE / XYLENES** | >99% | Sigma Aldrich / Local Hardware Store |
| **CHLOROFORM** | >99% | Sigma Aldrich |
| **PENTANE** | 98% | Sigma Aldrich |
| **HEXANES** | >99% | Sigma Aldrich |
| **MINERAL OIL + XYLENES** | 50% mineral oil<br>50% xylenes | Mixture of solvents listed above |
| **“MINERAL SPIRITS”** | *petroleum distillates | Local Hardware Store |
| **“V.M.&P. NAPHTHA”** | * Aliphatic naphtha | Local Hardware Store |
| **“LIQUID DE-GLOSSER”** | *aliphatic Naptha, toluene, acetone, isopropanol, ethylene glycon butyl ether | Local Hardware Store |
| **“WD-40”** | *aliphatic hydrocarbons, petroleum base oil, low vapor pressure aliphatic hydrocarbon, carbon dioxide | Local Hardware Store |
| **“GOO GONE”** | *Petroleum Distillates | Local Hardware Store |
| **WINDEX** | *isopropyl alcohol, ethylene glycol monobutyl ether, ammonia, dye, $H_2O$ | Local Hardware Store |
| **COMMERCIAL GASOLINE (REGULAR UNLEADED)** | *~90% small molecule petroleum distillates, and ~10% ethanol | Local Gas Station |